Results of the QUENCH-12 reflood experiment with a VVER-type bundle

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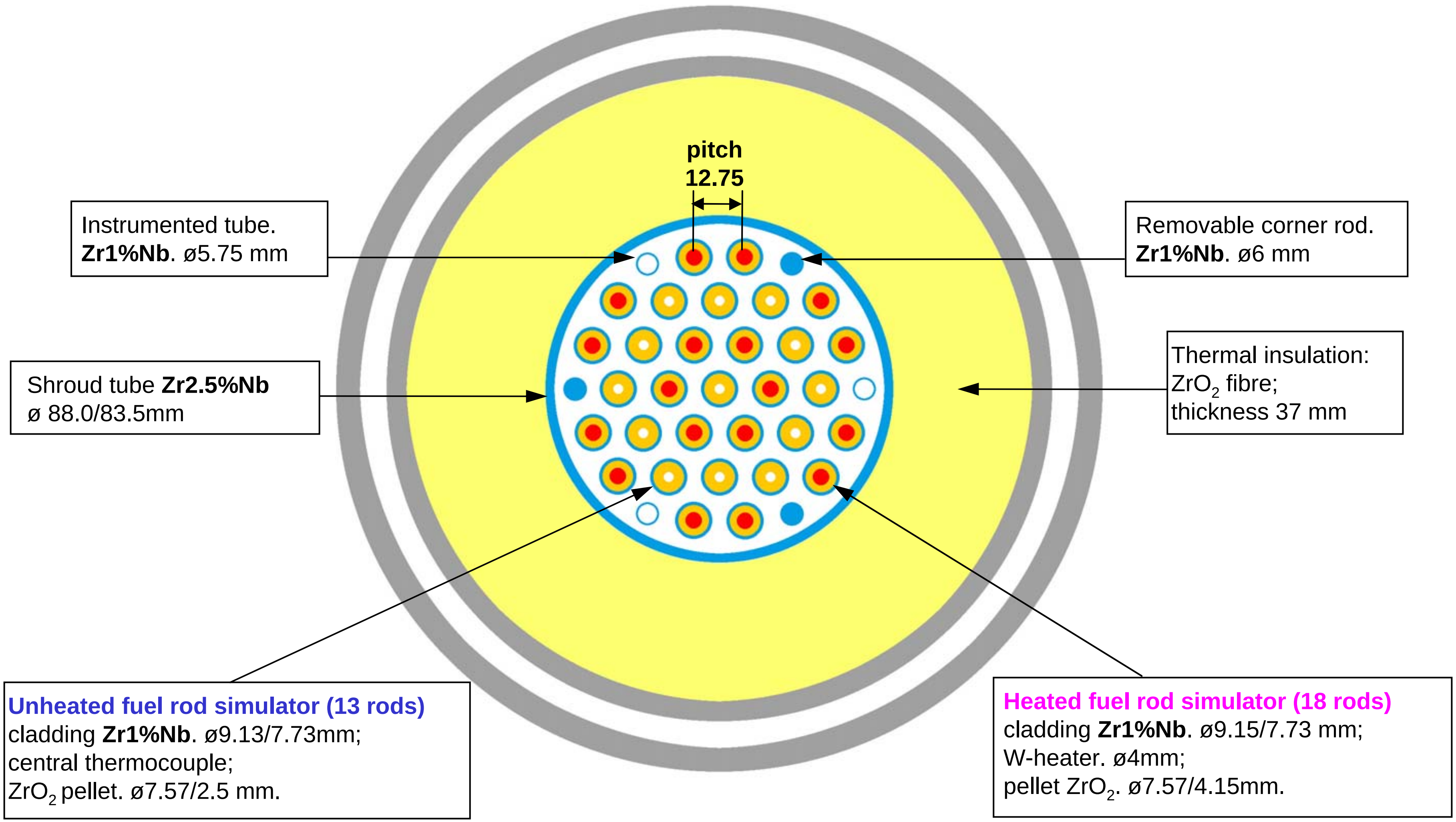
Objectives of the QUENCH-12 test

- **investigation of the effects of VVER materials and bundle geometry on core reflood**
- **comparison with the PWR bundle on the base of repeat of the test QUENCH-06 (ISP-45) scenario**

QUENCH-12: Cross section of the VVER-column.



Comparison of geometrical parameters of the QUENCH-12 bundle with the QUENCH-06 bundle:

1) **coolant channel area relationship Q12/Q06 = 1.09** ⇒ ***the fluid flow rate should be 9% higher for the Q12 bundle than for the Q06 bundle to provide the same flow velocity***

2) **metallic surface relationship Q12/Q06 = 1.22** ⇒ ***higher chemical energy production for the VVER bundle due to exothermic steam-metal reaction*;**

3) **bundle material mass relationship Q12/Q06 ~0.97** ⇒ ***the electrical power for the VVER bundle should be lower than for the Q06 bundle*.**

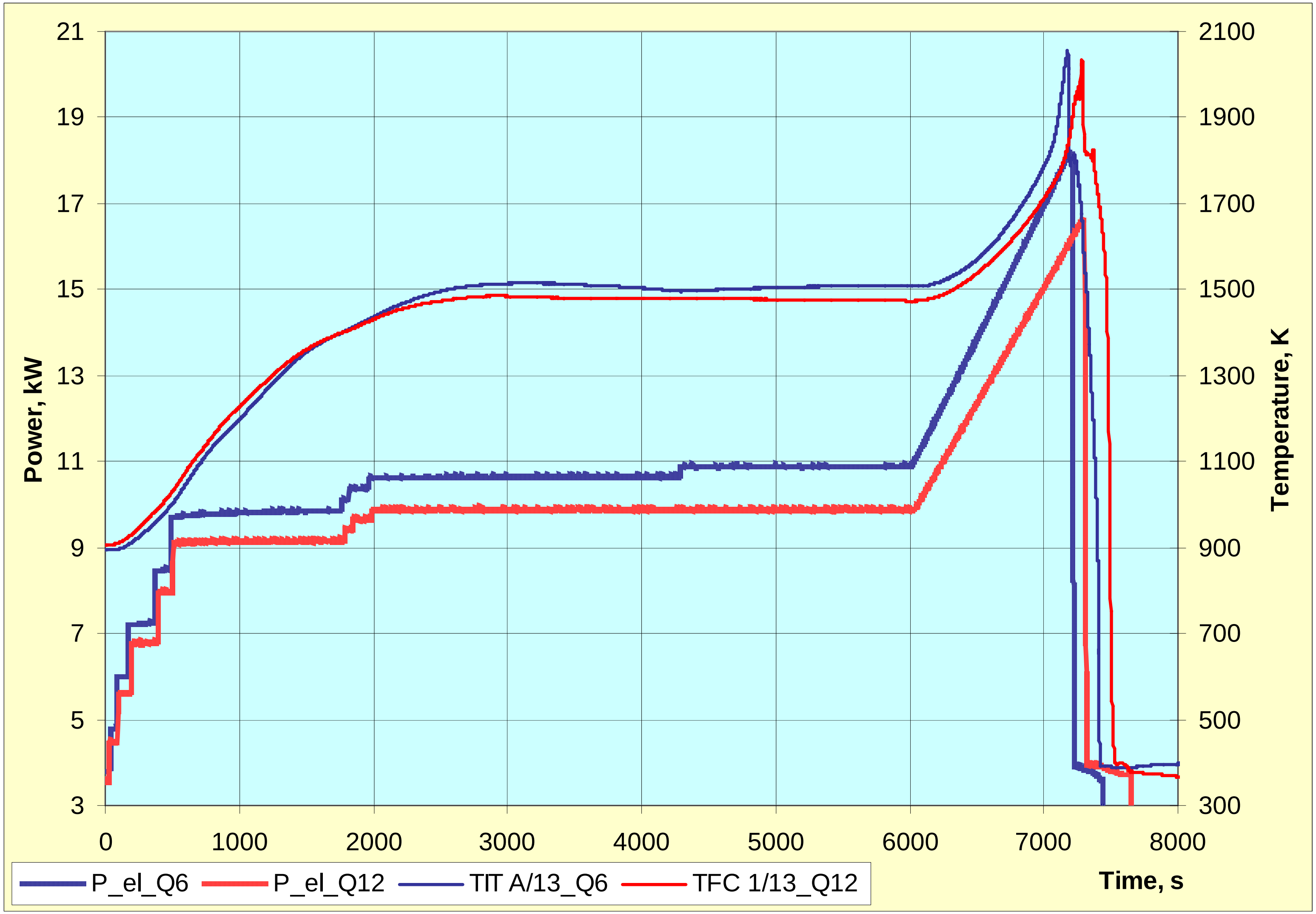
Pretest modelling support:

1. SCDAP/SIM simulations: J. Birchley, T. Haste, *Paul Scherer Institute, Switzerland***.**

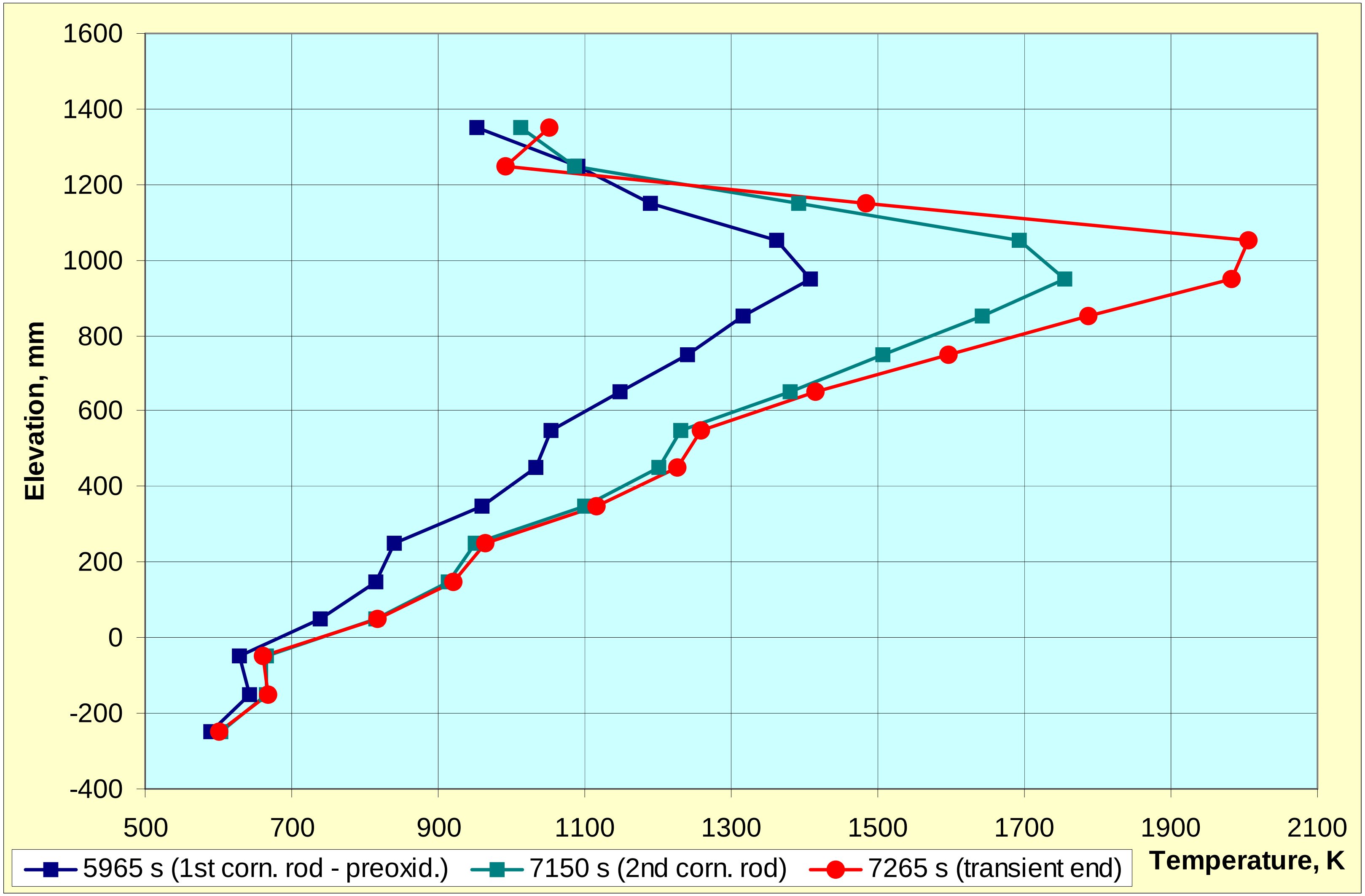
2. ICARE/CATHARE simulations: A. Volchek, Yu. Zvonarev, *Kurchatov Institute, Mosccow, with support from IRSN Cadarache***).**

The test was performed at the Forschungszentrum Karlsruhe on 27 September 2006

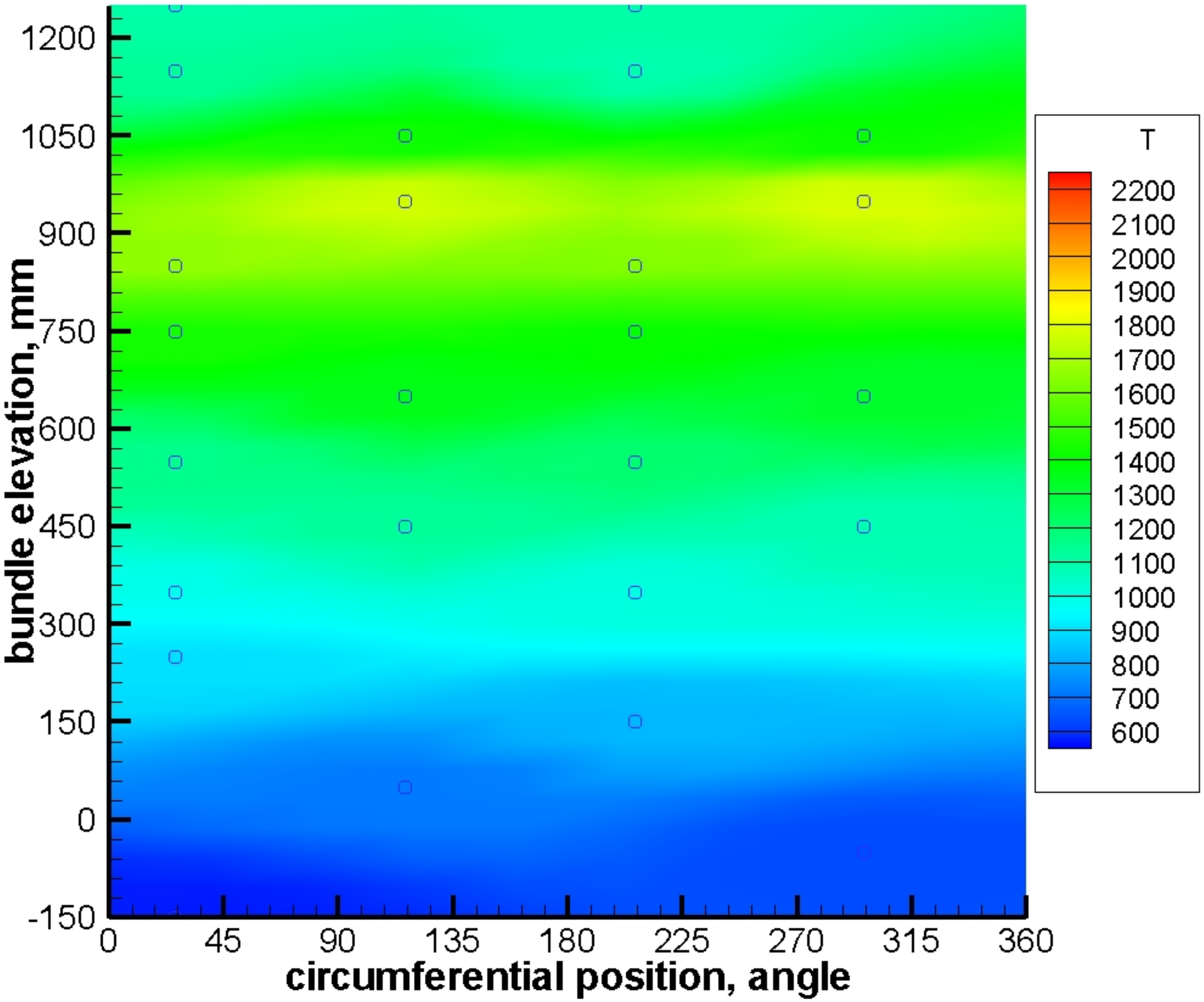
Comparison of temperature and power profiles for QUENCH-12 and QUECH-06.



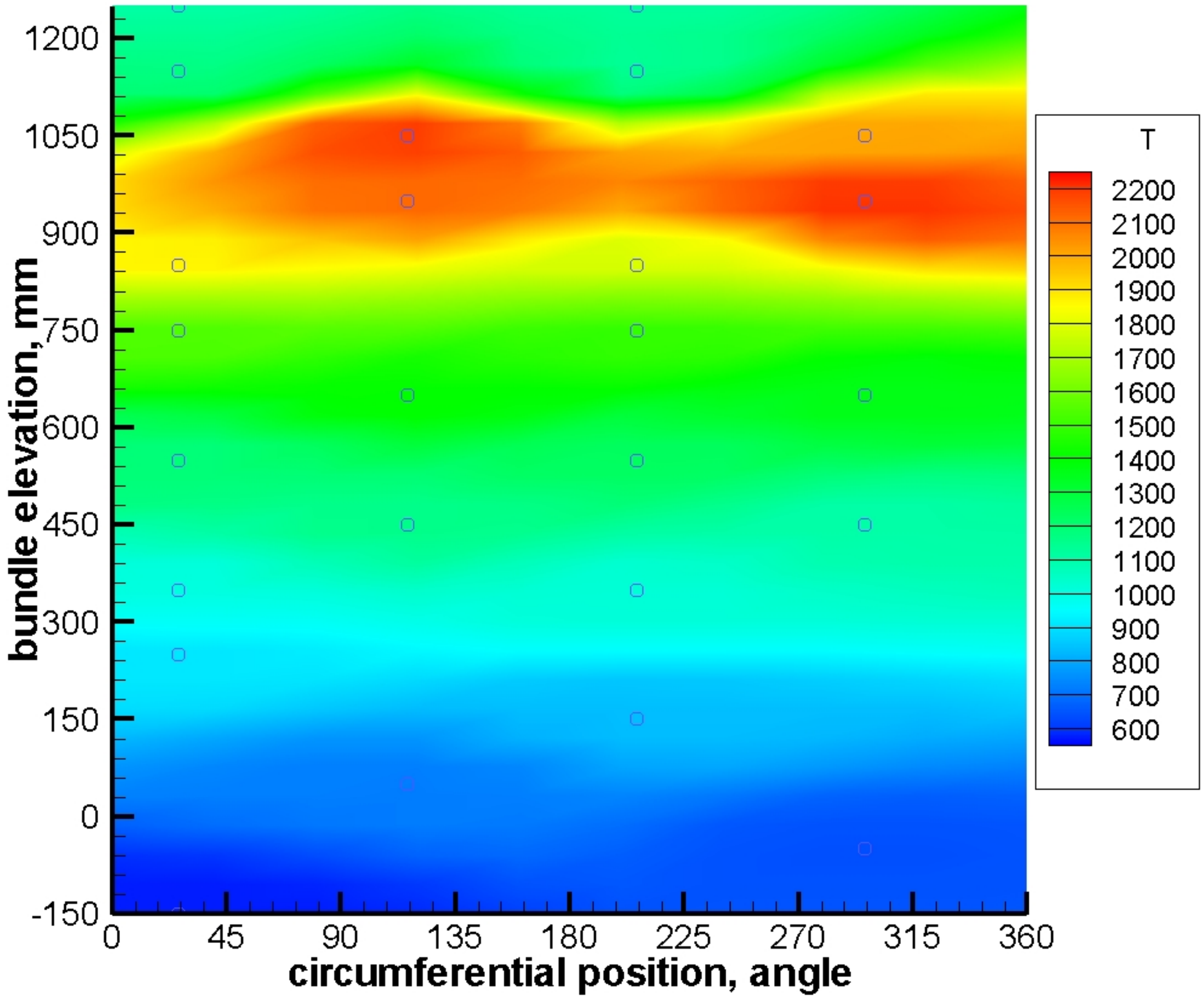
QUENCH-12: axial temperature profiles during pre-oxidation and transient phases



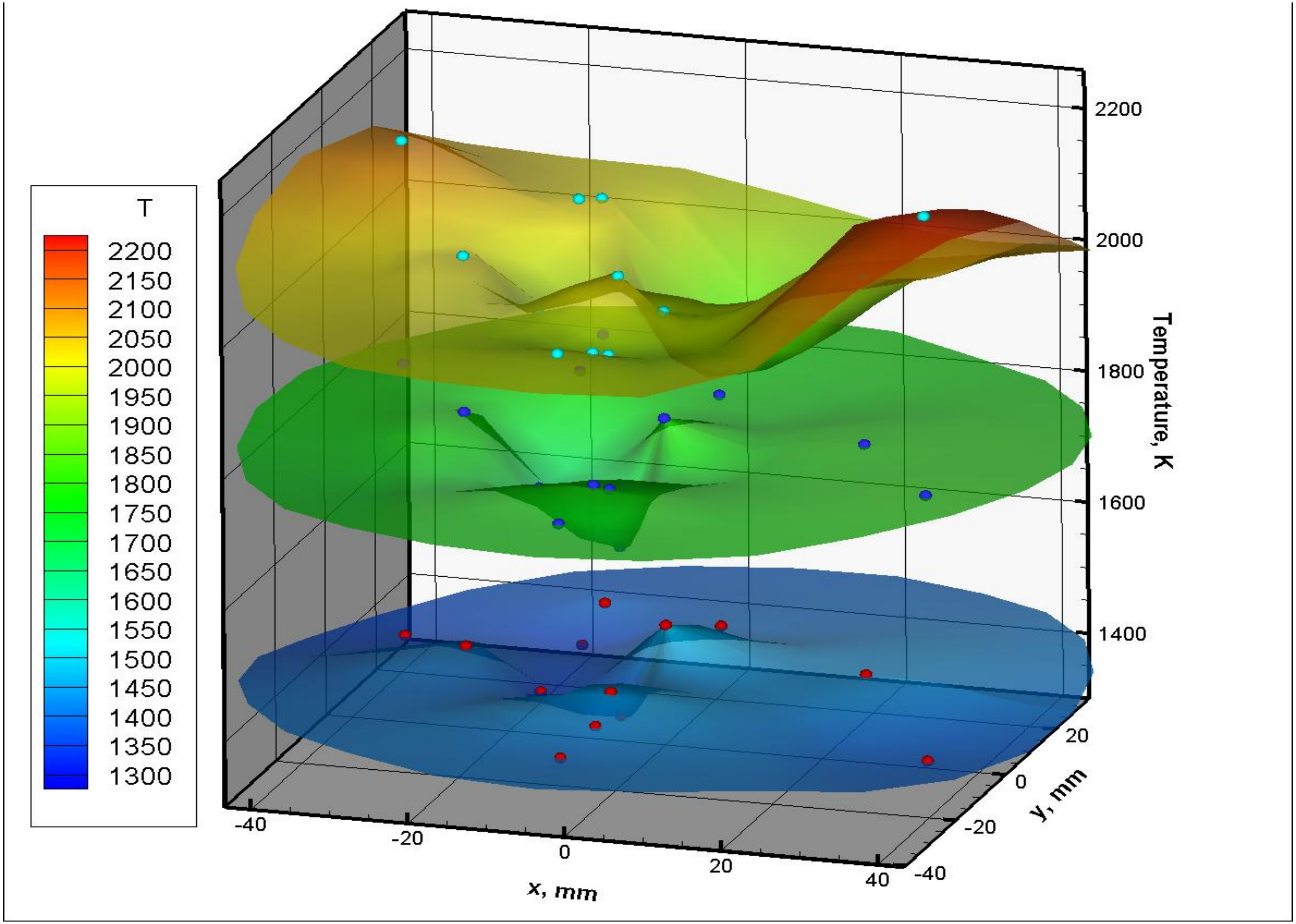
wrapped shroud: temperature field after begin of transient



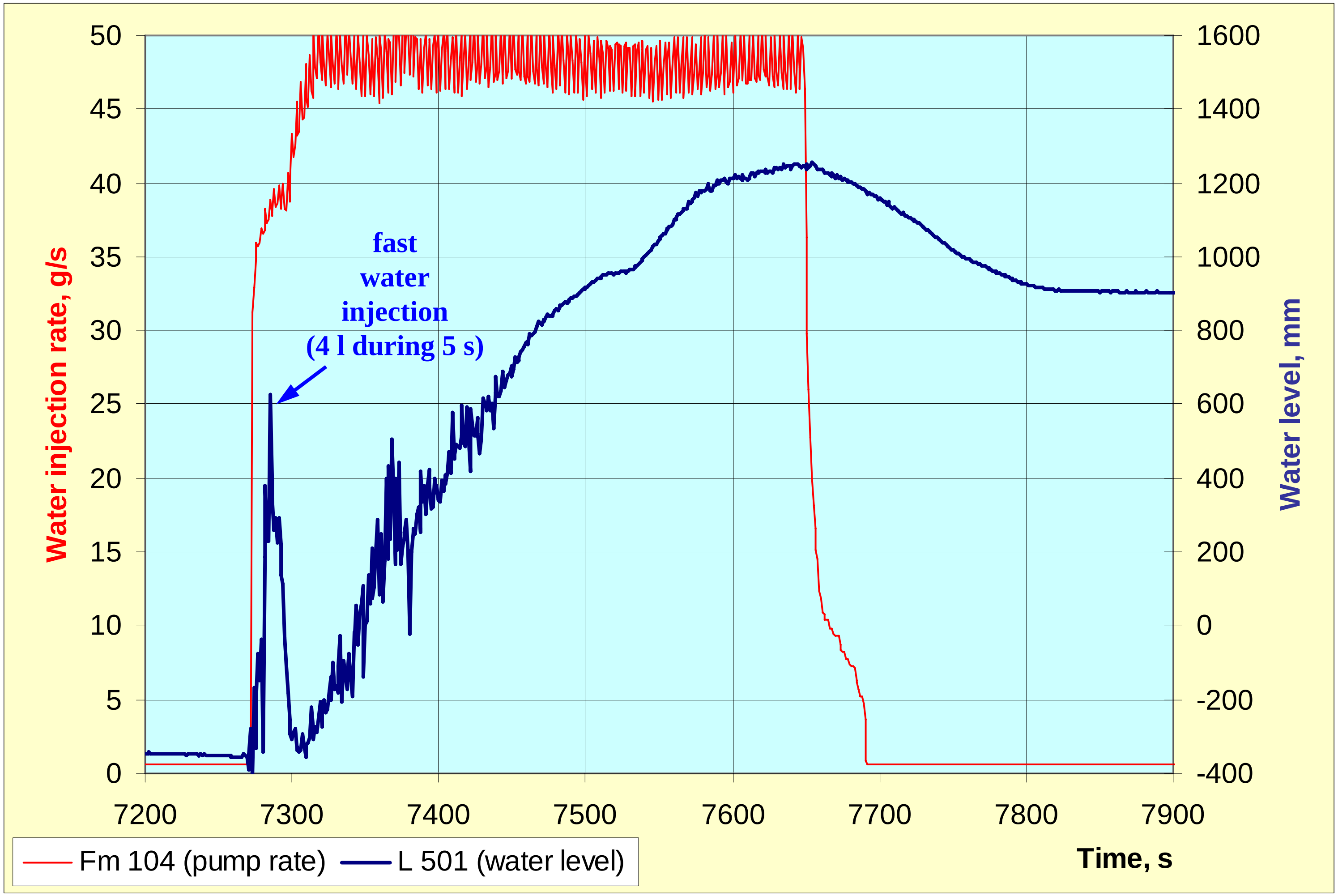
wrapped shroud: temperature field at end of transient



bundle temperature field: 1. during preoxidation, 2. after transient begin, 3. before reflood

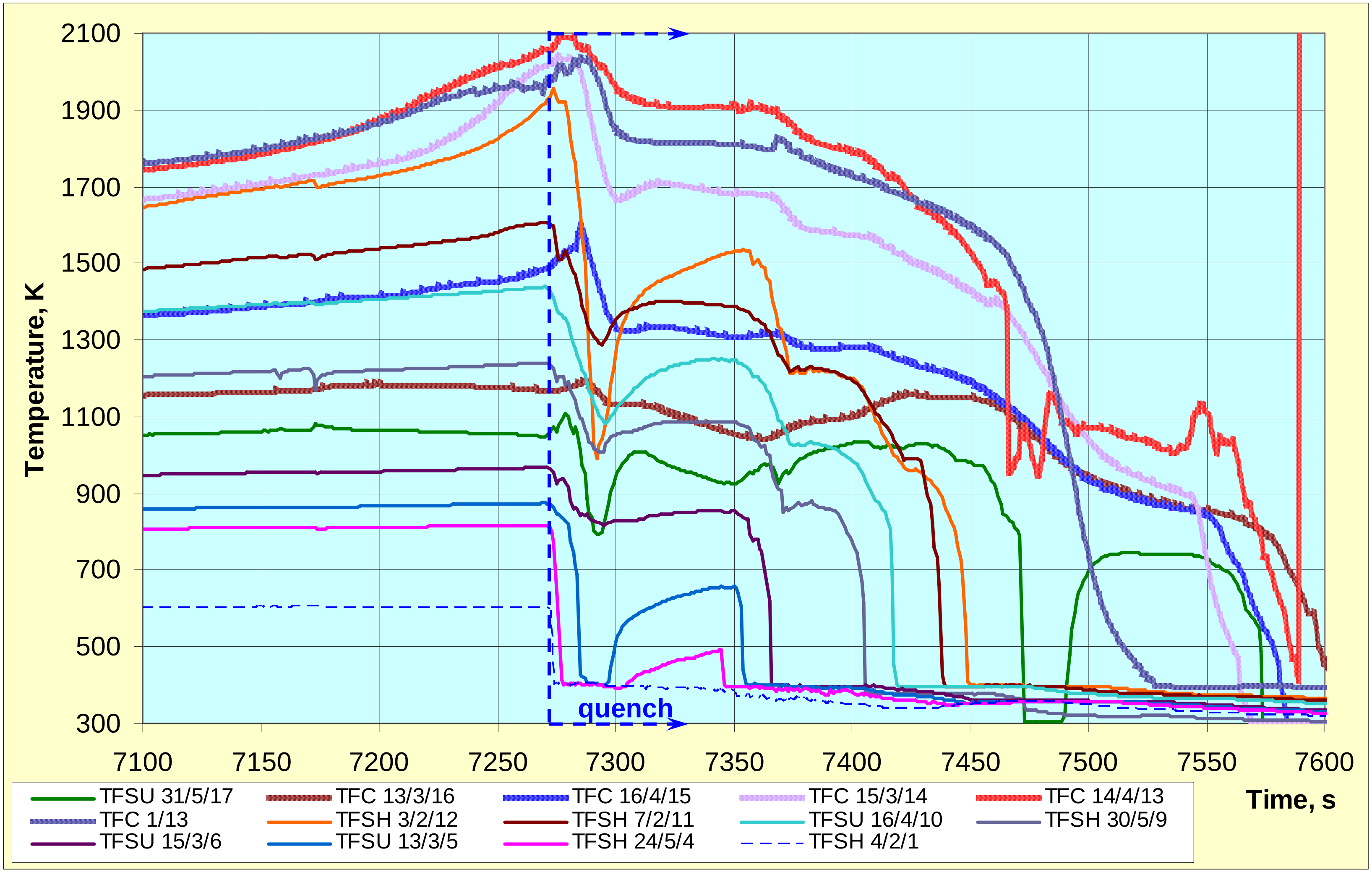


QUENCH-12, quench phase: water injection

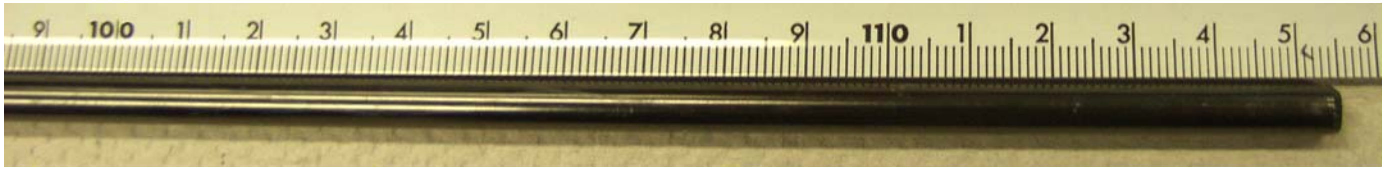


QUENCH-12, quench phase: selected reading of the bundle thermocouples.

Temporary sharp decrease of the cladding surface temperature as reaction on the fog from the water fast injection system. Pellet internal thermocouples show smooth cooling of the bundle during ~350 s.



QUENCH-12: withdrawn corner rods



corner rod B after pre-test (800 °C, oxide layer thickness less of 5 µm)

B
F
D

corner rods D, F, B after pre-test: spalling of the outer skin of oxide layer.
D – withdrawn after pre-oxidation,
F – withdrawn before reflood,
B – withdrawn after test.

QUENCH-12: axial sections of different ZrO_2 spalling intensity on withdrawn corner rods

B
after test

F
before
reflood

D
after
preoxidation

F

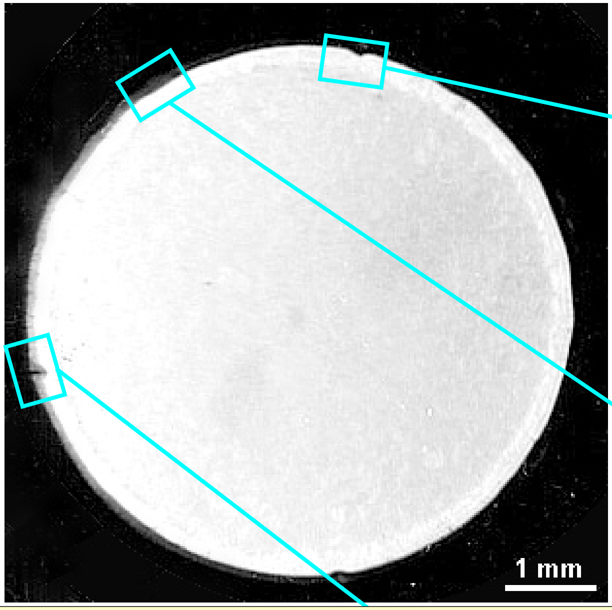
D

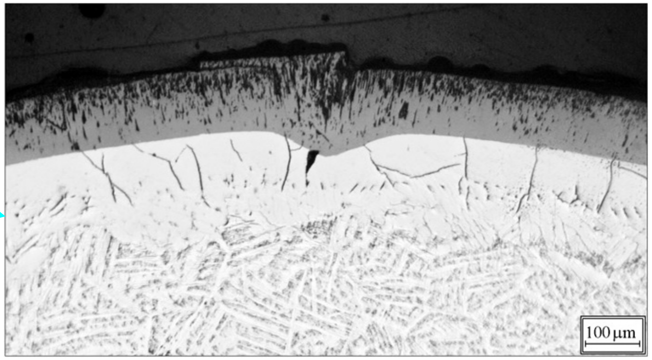
F

D

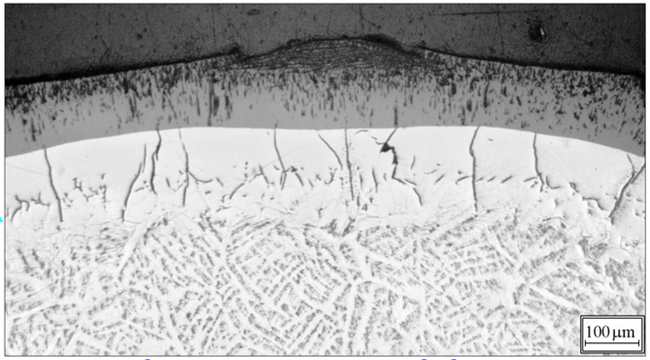
rod D: cross-section at elevation of 940 mm, total diameter 6070 µm

Metallography performed at RIAR

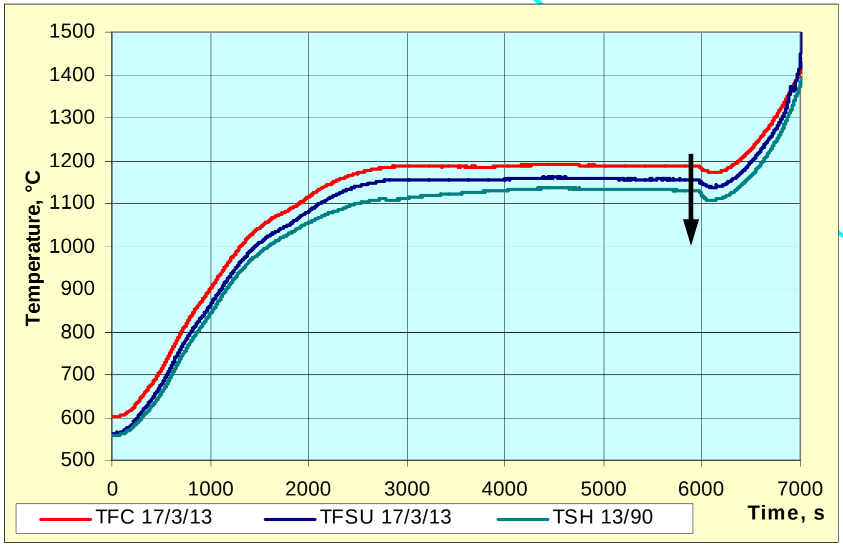


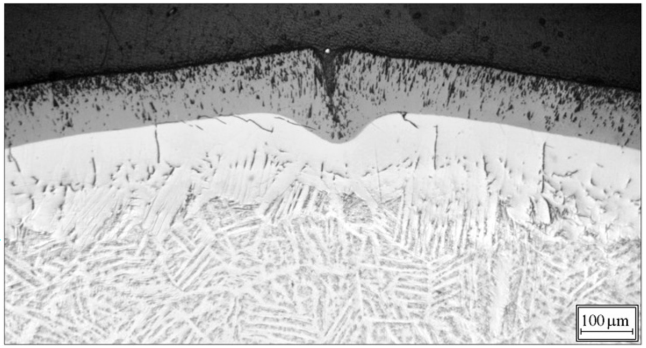


ZrO_2 layer 75 µm, α-Zr(O) 105 µm



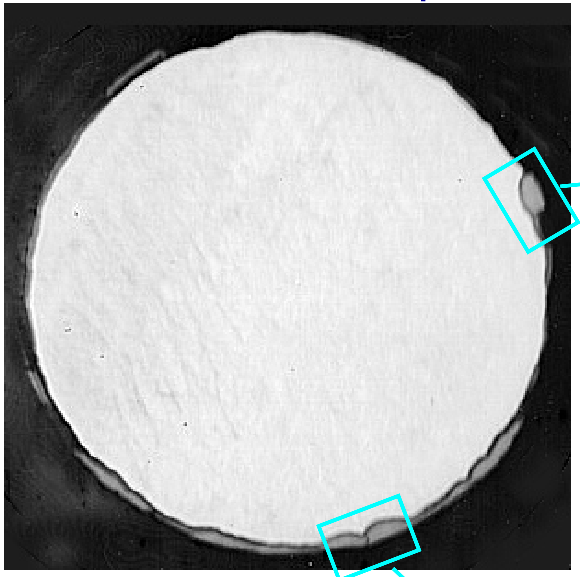
ZrO_2 layer 115 µm, α-Zr(O) 145 µm



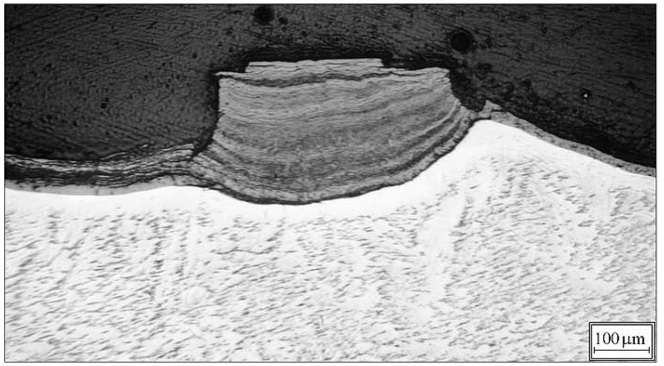


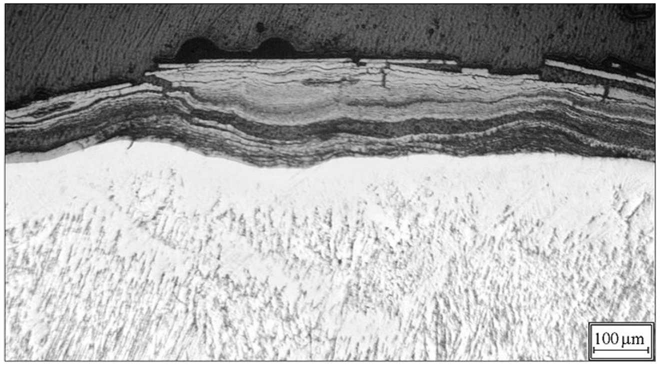
ZrO_2 layer 105 µm, α-Zr(O) 135 µm

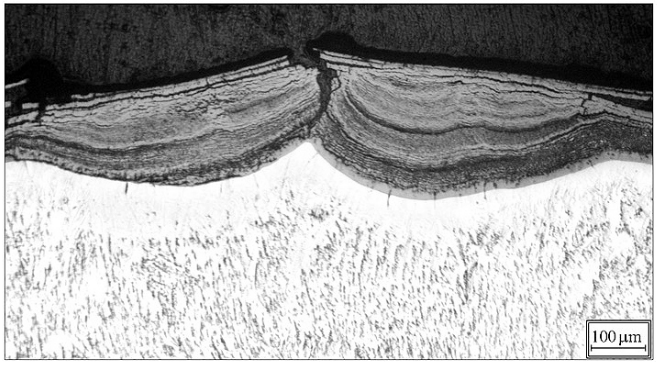
rod F: cross-section at elevation of 700 mm, total diameter 6050 µm

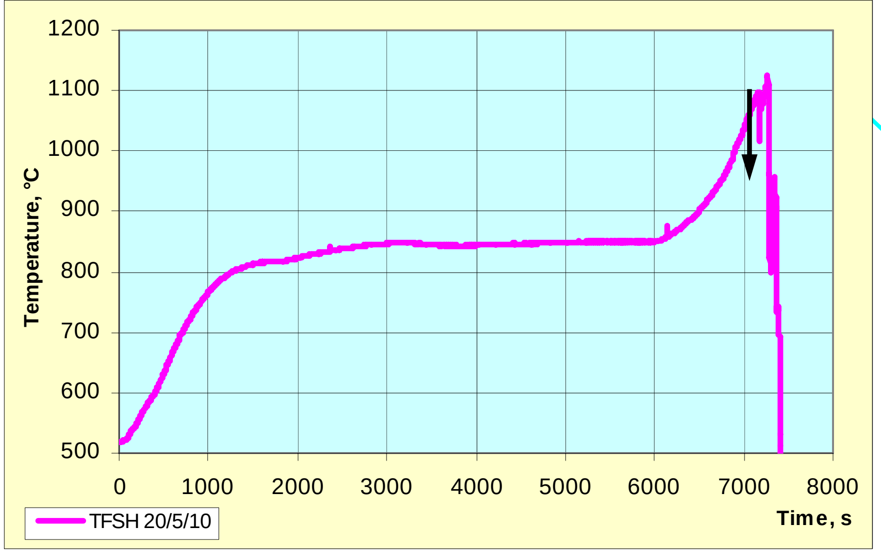


Metallography performed at RIAR



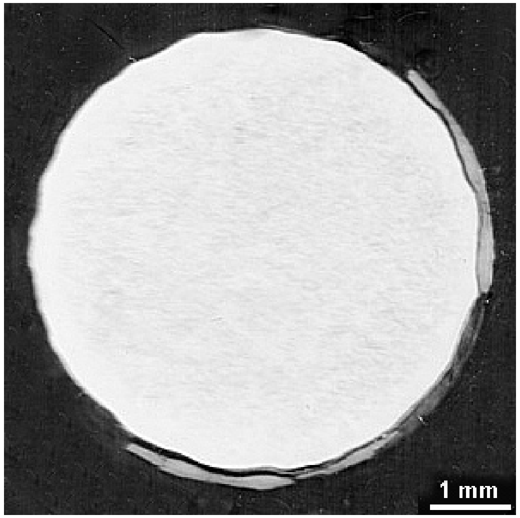




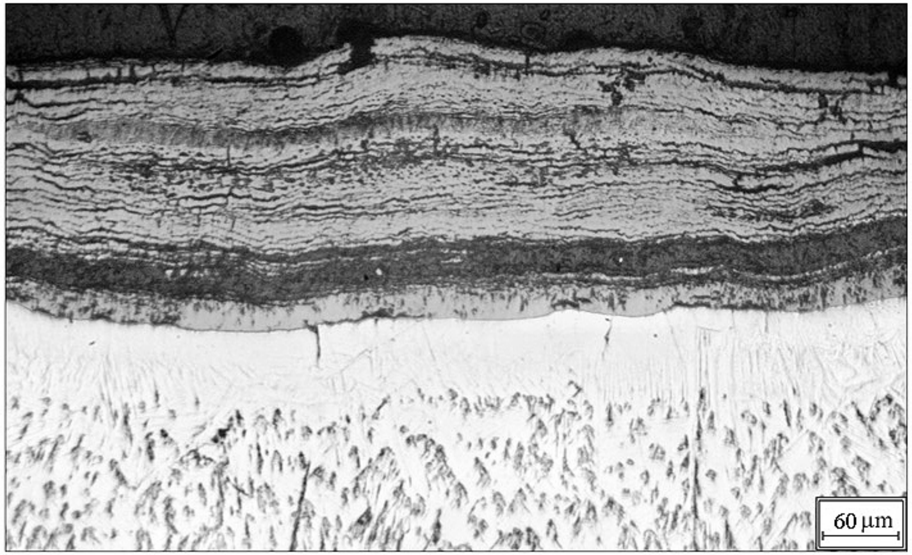


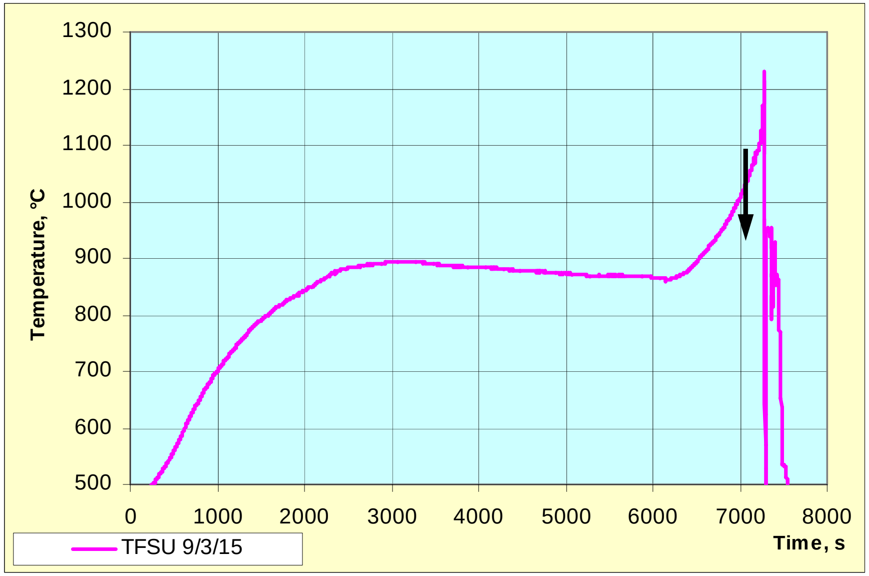
not homogeneous breakaway oxidation

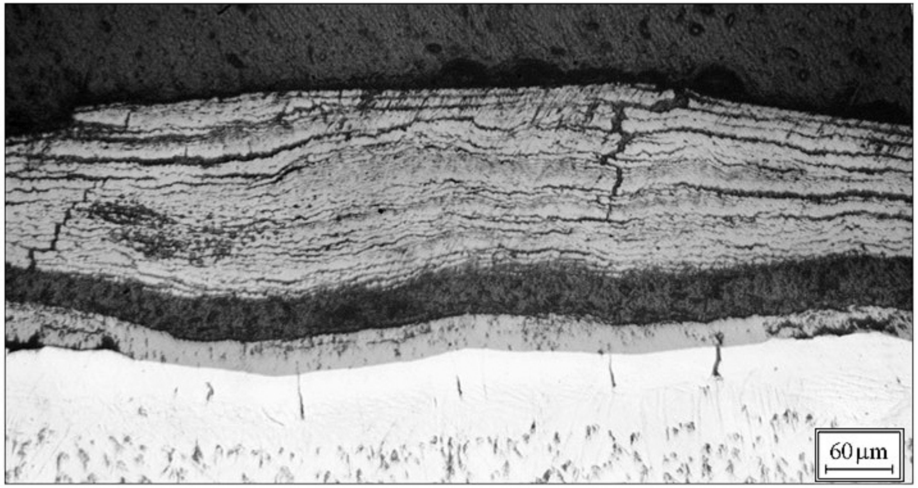
rod F: cross-section at elevation of 1120 mm, total diameter 6050 µm



Metallography performed at RIAR

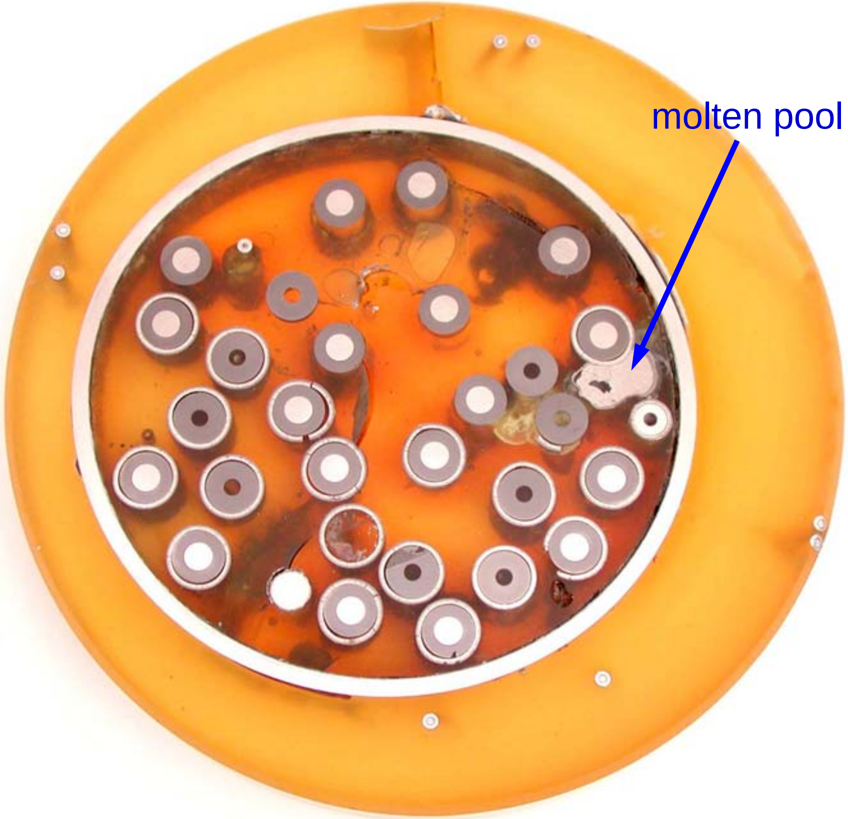




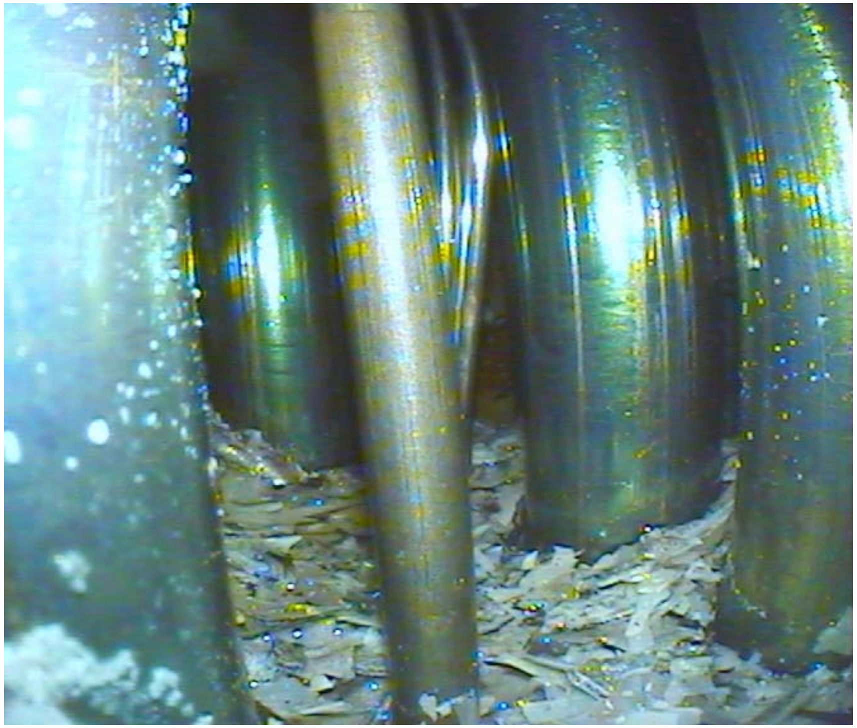


formation of multilayer oxide structure due to breakaway oxidation

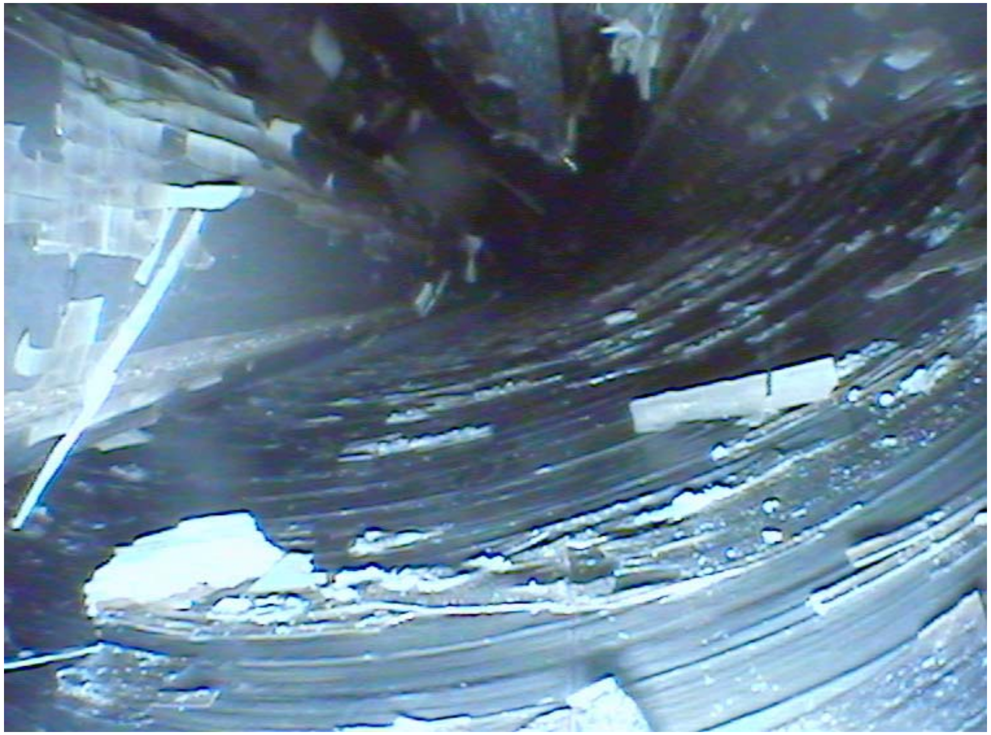
QUENCH-12: cross-sections of the bundle (top view)

	
Elevation 550 mm: debris bed on spacer grid	Elevation 854 mm: loss of bundle geometry and melt formation

QUENCH-12, videoscope analysis: intensive oxide scale spalling inside of bundle

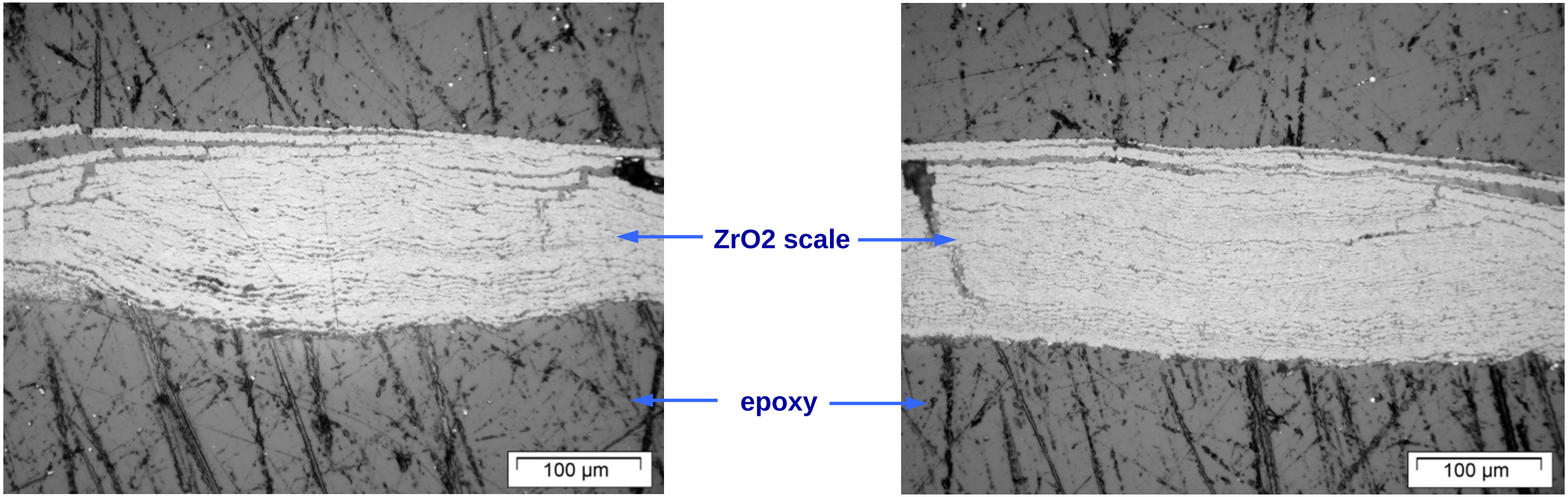


side view from corner rod B
on the top of the first spacer (-150 mm)



camera in position of corner rod D at 650 mm:
spalled oxide scales at shroud and cladding

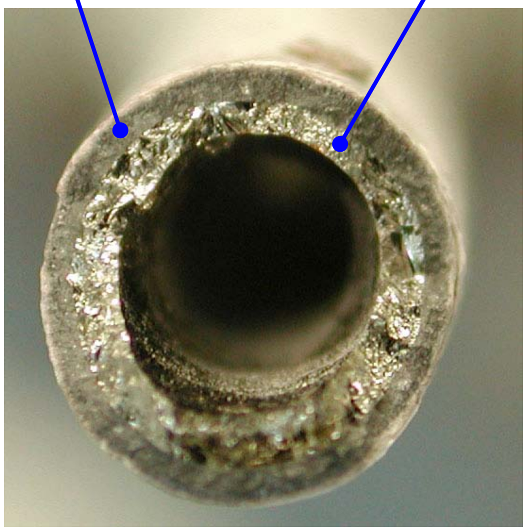
QUENCH-12: laminated structure of spalled oxide scales



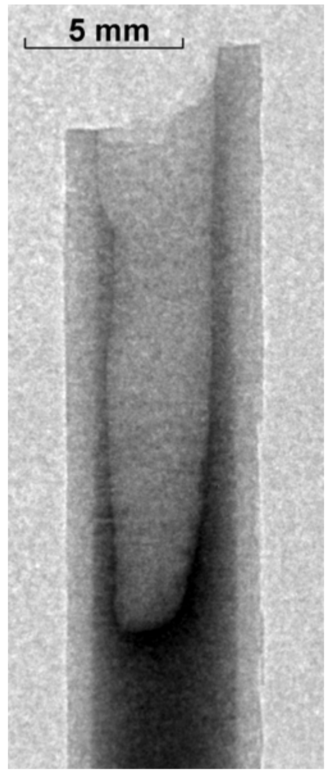
QUENCH-12: melt formation at 850 mm on the position of withdrawn corner rod B.

ZrO_2 layer ~500 µm

α-Zr(O) layer ~650 µm



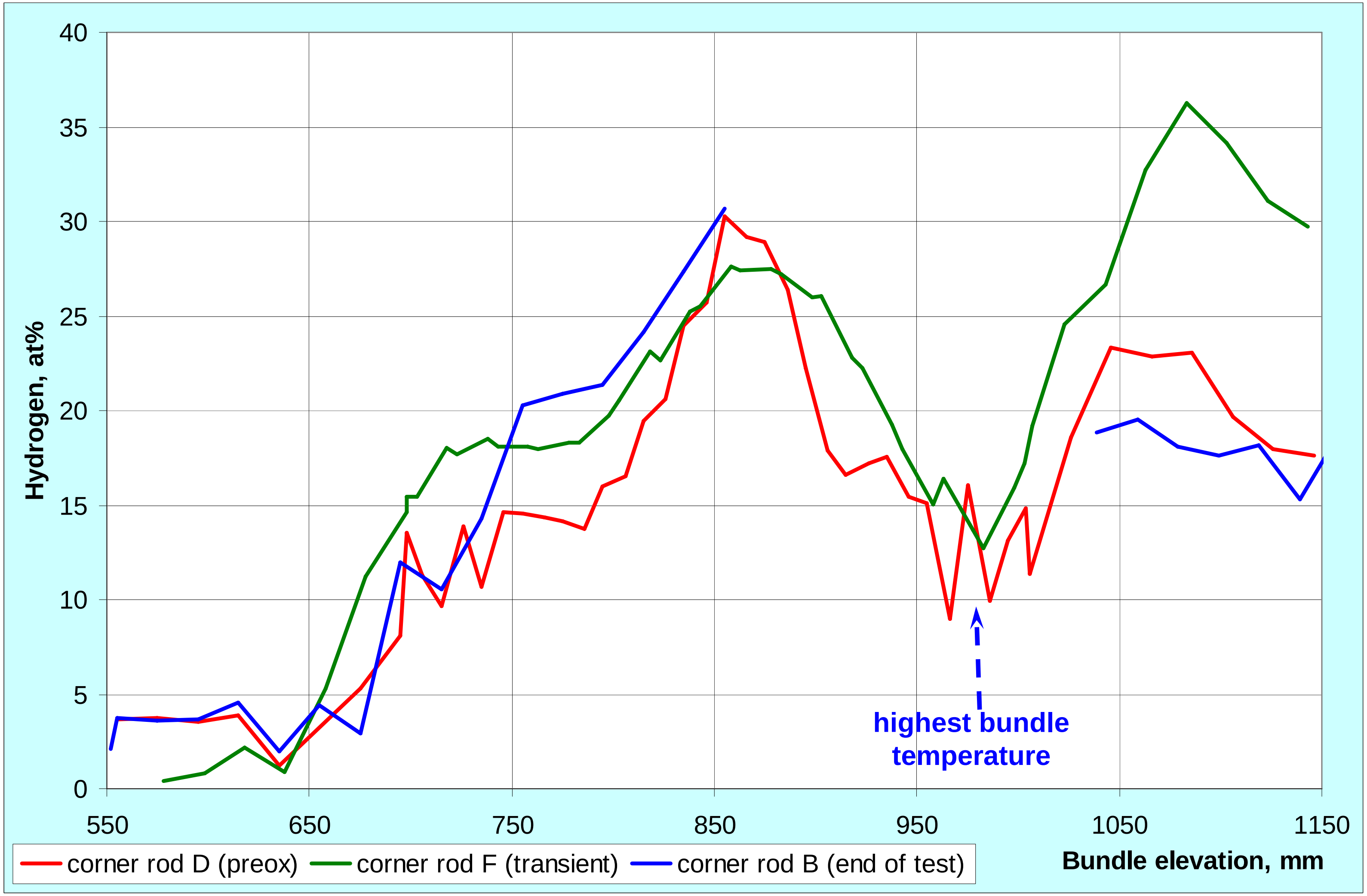
upper part of the rod B: is the absent central part the melted β-Zr?



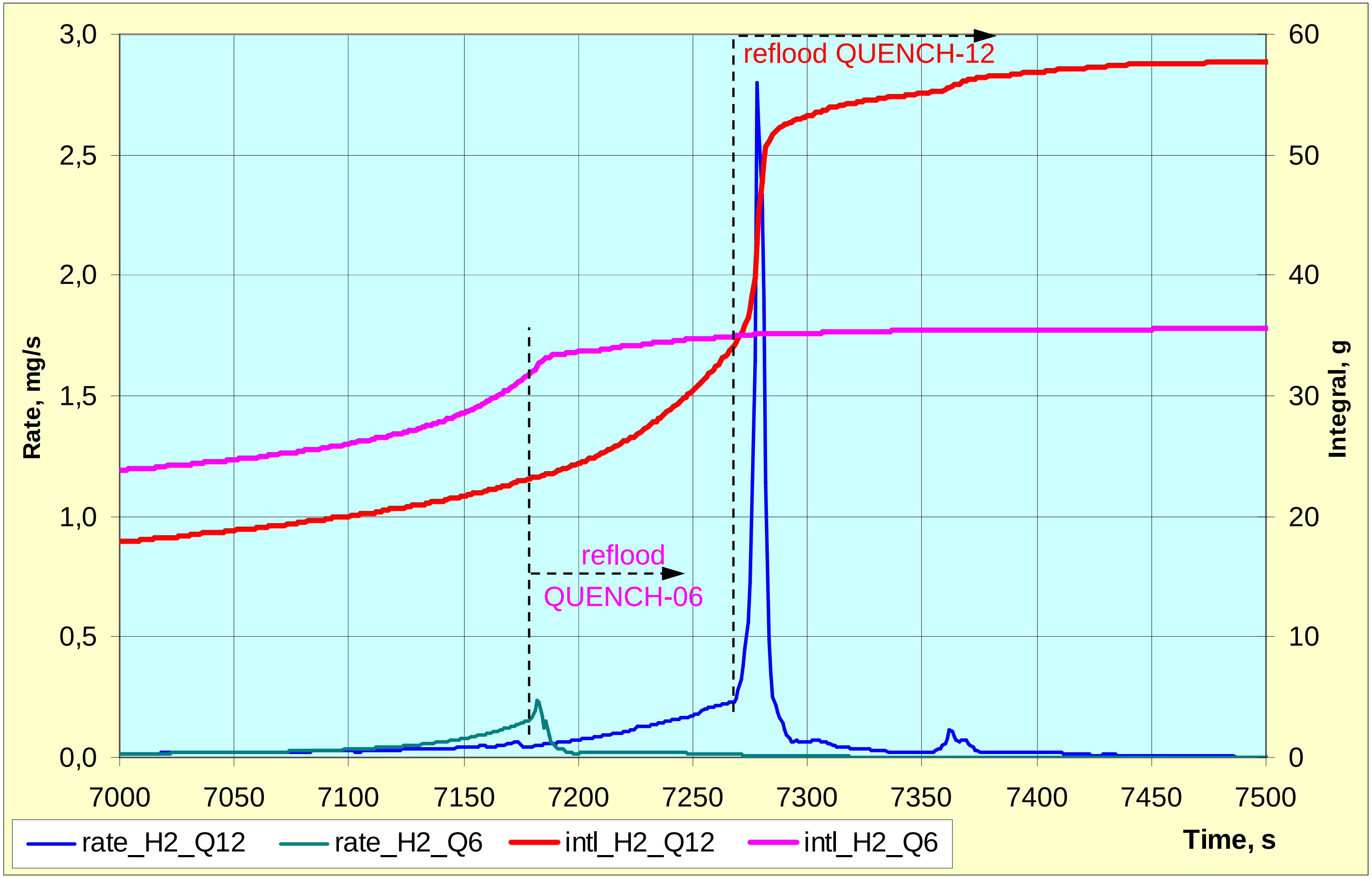
neutron radiography (M. Große) shows the deep hole with irregular diameter

melt formation in bundle at the break position of the corner rod B (850 mm)

QUENCH-12: hydrogen uptake by corner rods /results of neutron radiography/



Comparison of hydrogen release during QUENCH-12 and QUECH-06.



QUENCH-06: H_2 production before reflood 32 g, during reflood 4 g

QUENCH-12: H_2 production before reflood 34 g, during reflood 24 g

SUMMARY (1)

- The QUENCH-12 experiment investigated the effects of VVER materials and bundle geometry on core reflood, in comparison with test QUENCH-06 (ISP-45) with Western PWR geometry**.**

- The preliminary test at the maximum temperature 800°C was performed. The corresponding oxidation was negligible: less of 5 µm. The results of this test were used to fine attenuation of the pretest modelling.

- The electrical power changing during the test corresponds completely to calculated values up to reflood phase. The temperature history during preoxidation is very similar to the QUENCH-06 temperature history.

- Two corner rods were withdrawn at the end of preoxidation and transient phases correspondingly. The third corner rod was withdrawn after the test. The surface of the rods shows intensive traces of the break-away effect influence. Many oxide scales with thickness about 100 µm were spalled during withdrawn.

- The surfaces of the rod simulator and shroud evident also influence of the breakaway oxidation. However the ZrO_2 scales spalling is fewer intensive than by corner rods. Possible reasons can be 1) different mechanical properties of tube and massive rod; 2) other surface preparation of cladding and rods.

SUMMARY (2)

- Following reflood initiation, a moderate temperature excursion of ca. 50 K was observed, over a longer period than in QUENCH-06**.** The temperatures at elevations between 850 mm and 1050 mm exceeded the melting temperature of β-Zr.

- The hydrogen content in the corner rods reached a value more than 30 at% at the bundle elevations of 850 and 1100 mm.

- The total hydrogen production was 58 g (for QUENCH-06: 36 g), during the reflood was released 24 g hydrogen (for QUENCH-06: 4 g). This may be attributed partly to the longer excursion time in QUENCH-12. Other reasons for the increased hydrogen production may be extensive damaging of the cladding surfaces due to the breakaway oxidation and local melt formation with subsequent melt oxidation.

Success of the work was possible due to

- excellent engagement of all participants
- quick management measures of ISTC
- permanent support of CEG-SAM group

Thank you!